THE T980 CRYSTAL COLLIMATION EXPERIMENT AT THE TEVATRON

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Fermilab

4th Crystal Channeling Workshop
CERN, Switzerland
March 24-27, 2009

OUTLINE

- T980 Mission and 12-month Retrospective
- Installation of Characterized O-shaped Crystal, Improved Goniometer and Enhanced Diagnostics
- End-of-Store Beam Studies
- First Full Collider Store with Crystal (!)
- Progress on Simulation Front
- Status of New Two-Crystal Goniometer
- Study Plans

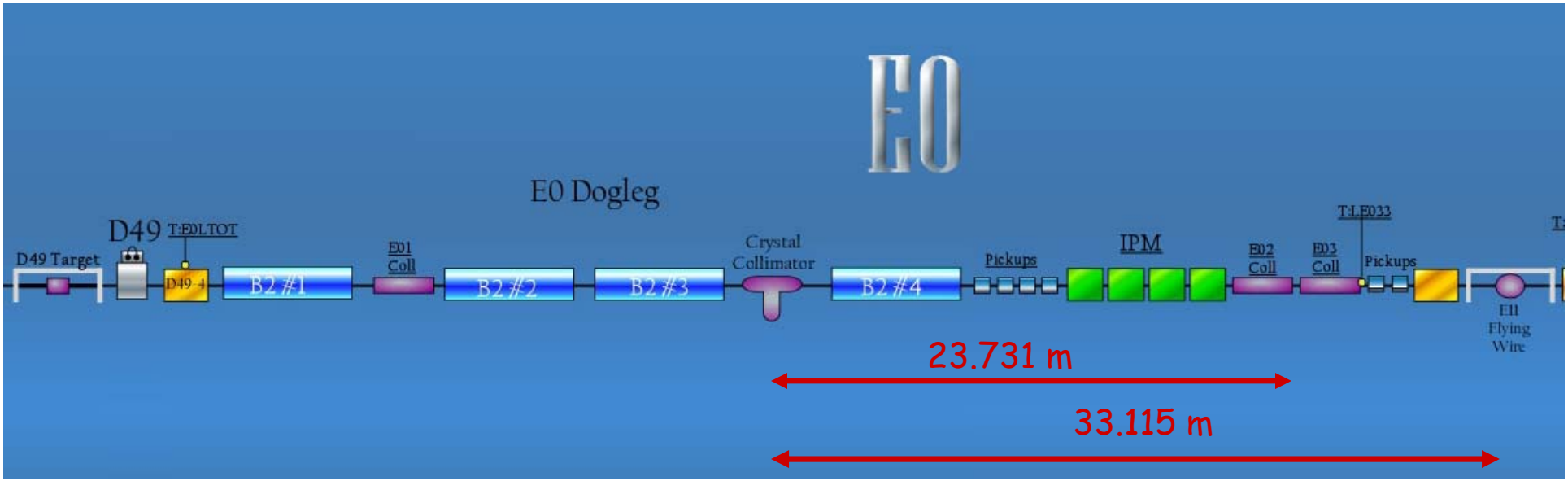
T980 MISSION

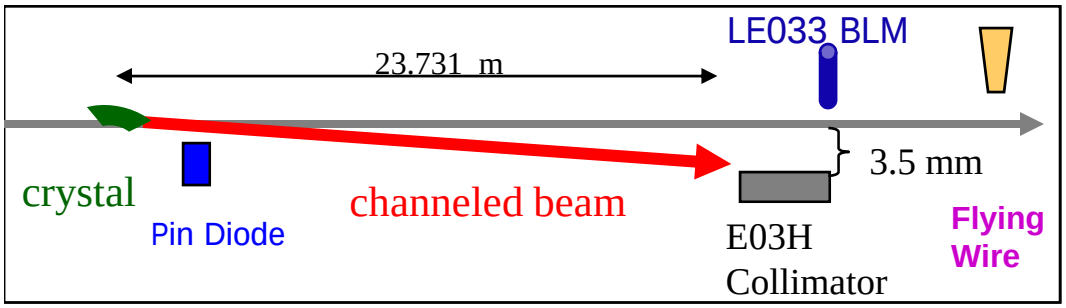
❖ Develop a collimation system for hadron colliders based on channeling crystal techniques, which has a promise to reduce machine impedance, beam losses in superconducting magnets, improve background conditions in the collider detectors and be compatible with heavy-ion operation.

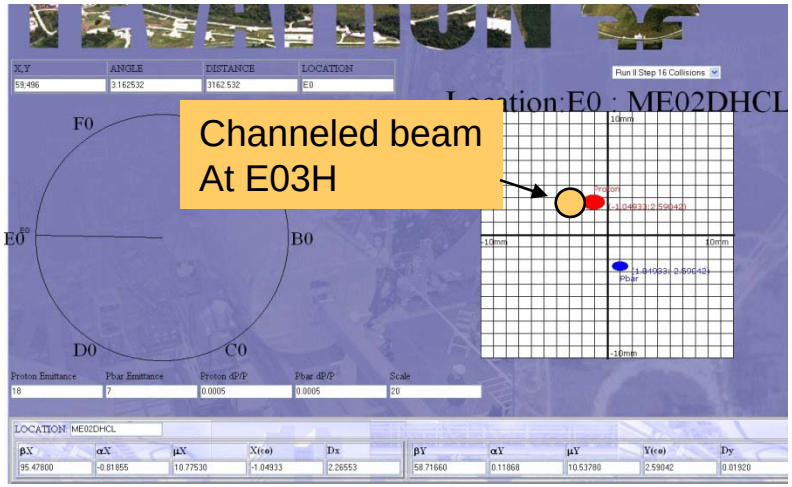
❖ Start routine use of crystal collimation in the entire Tevatron collider store.

❖ Study the system's performance and underlying beam dynamics exploiting the unique possibility provided by the Tevatron collider to evaluate an engineering implementation of this technique in the LHC.

E0 Crystal Collimation Layout







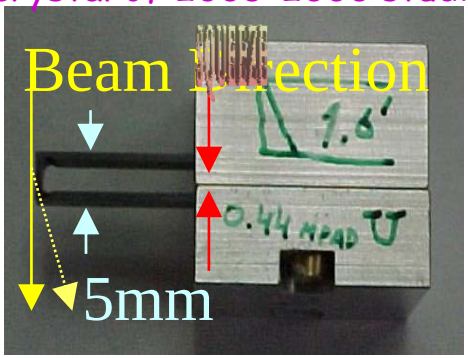
12-MONTH RETROSPECTIVE

Last 12 months have been full of significant events for T980:

- Installation of substantially improved goniometer, proven/characterized crystal and enhanced beam diagnostics
- Interesting End-of-Store studies **culminating last week in the first use of the crystal collimation system through the entire Collider store !**
- Simulation tool developments which allowed to get valuable predictions on the system performance
- Launch of a new push-pull goniometer project

CRYSTAL ANALYSIS AND REPLACEMENT

"Successful" 0.44mrad O-shaped crystal of 2005-2006 studies



"Unsuccessful" 0.15mrad strip crystal of 2007 studies

Suspicious strip crystal and unstable goniometer were removed from the tunnel in December 2007 after several unsuccessful attempts during the year. After cooldown, the crystal was shipped to Italy last week for its analysis.

The O-shaped crystal of successful studies of 2005 was shipped to Europe in January 2008 for its characterization.

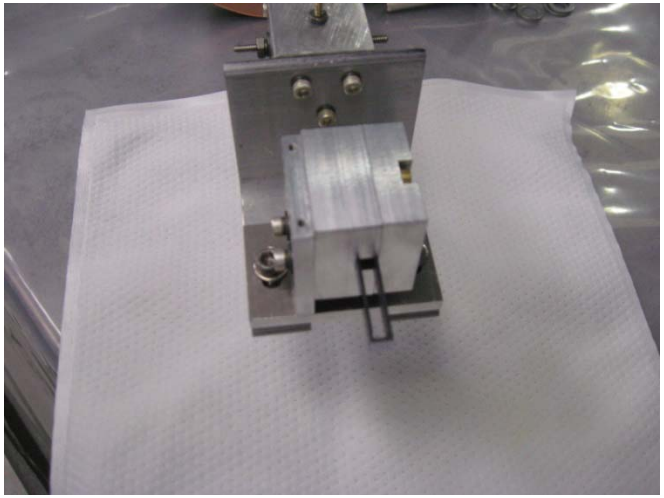
Analysis with 2-MeV He+ ions performed by V. Guidi at Ferrara, INFN, has shown that quality of the surfaces is very good, and it needs no treatment.

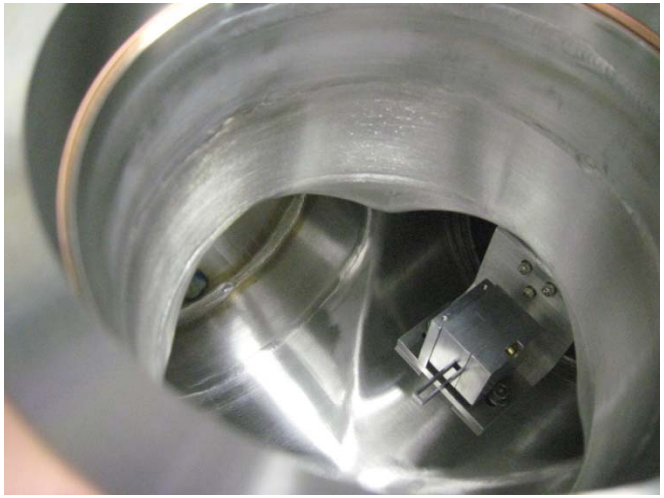
X-ray measurements of bending angle and miscut angle with 5% accuracy performed by Yu. Ivanov, PNPI; the angles are 0.41±0.02 mrad and 1.6±0.1 mrad, correspondingly.

The crystal received back in April and is now installed in the Tevatron tunnel.

GONIOMETER MODIFICATIONS (1)

- Deleted angular swing motion inchworm motor and limit switches
- Deleted internal angular motion LVDT
- Deleted ball-screw type horizontal insertion drive slide
- Deleted electric brake on horizontal motion
- Removed strip crystal, installed original O-shaped RHIC crystal again
- Repaired vibration problem with crystal mounting bracket
- Repaired dragging arm problem with angular swing motion

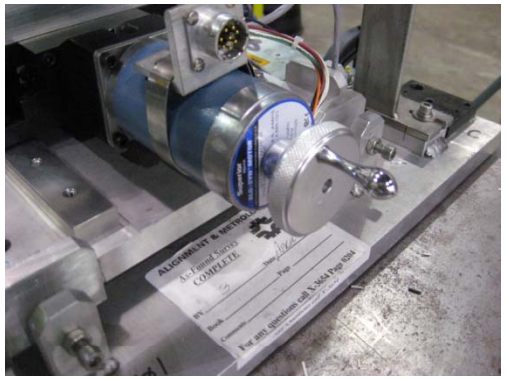




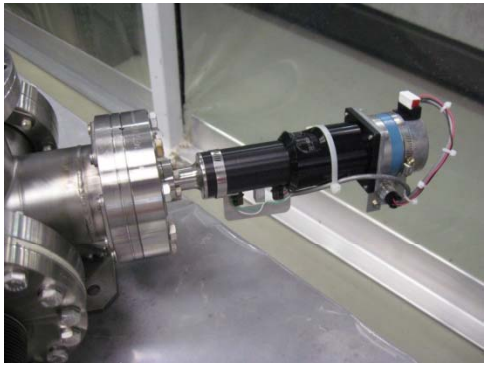
R. Reilly, A. Legan

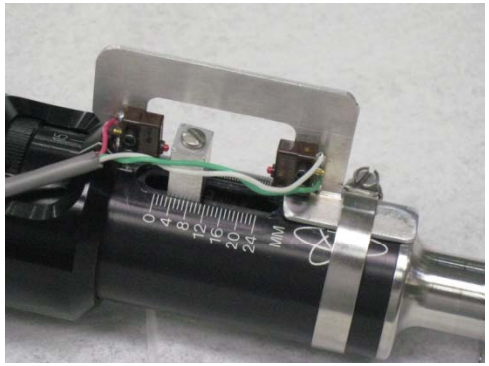
GONIOMETER MODIFICATIONS (2)

- New horizontal insertion drive slide is self-locking lead-screw type, not affected by vacuum load.
- New horizontal insertion drive stepper motor with hand crank, in case of motor or controls failure the crystal can be cranked out of the beamline by hand; linear motion .00005" per step.



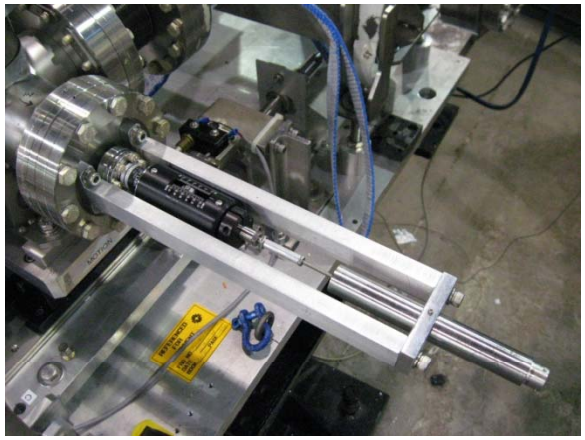
- New angular swing motion linear actuator vacuum feedthru with external stepper motor and limit switches, thumbwheel for hand operation; angular positioning of the crystal in steps of 1.36 urad.

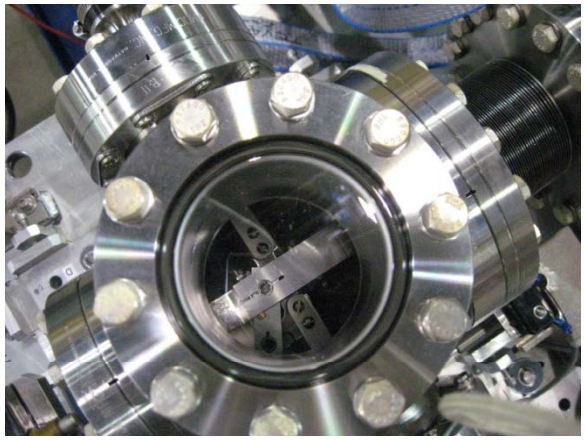




GONIOMETER MODIFICATIONS AND INSTALLATION

- New linear feedthru with external LVDT and visual position indicator for angular swing motion; angular measurement 2.1 urad.
- Glass viewport to observe angular swing motion.





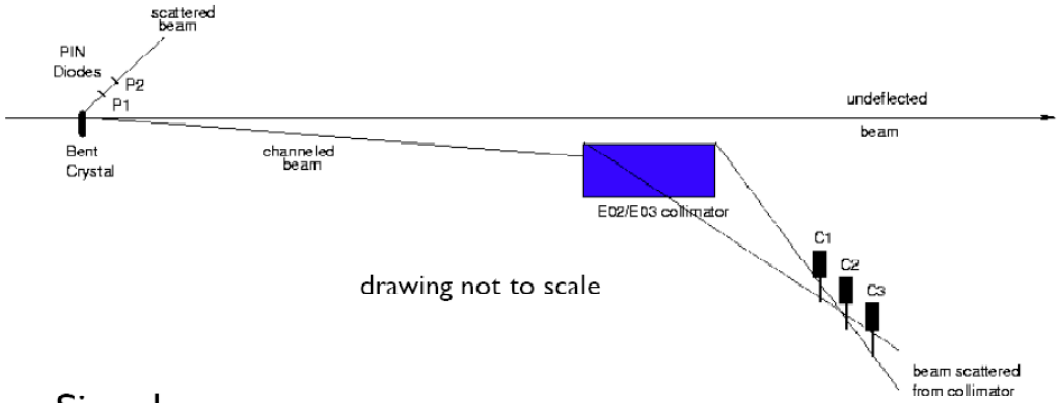
Operated under vacuum
Vacuum chamber baked
Vacuum certified
Installed in 12 hr access

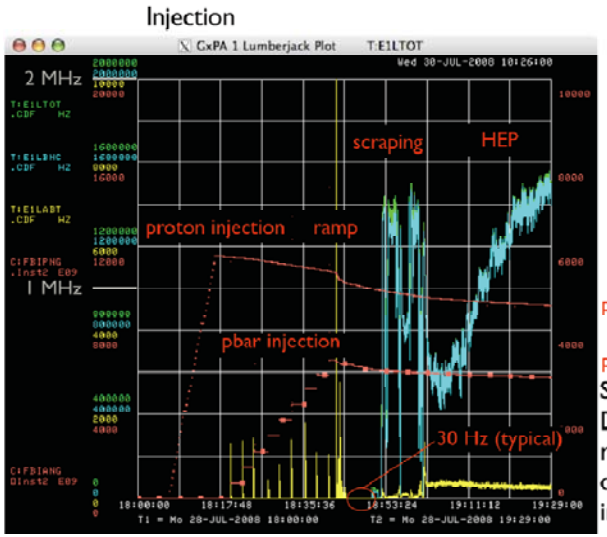
R. Reilly

BEAM DIAGNOSTICS ENHANCEMENTS

- 1-cm^2 PIN diodes immediately downstream xtal arranged in telescope
- LE033 beam loss monitor (~24 m downstream)
- E0CH (EI) scintillation counter telescope
- E11 flying wires (~33 m downstream)
- CDF beam loss monitors (~3 km downstream)

E0CH COUNTERS



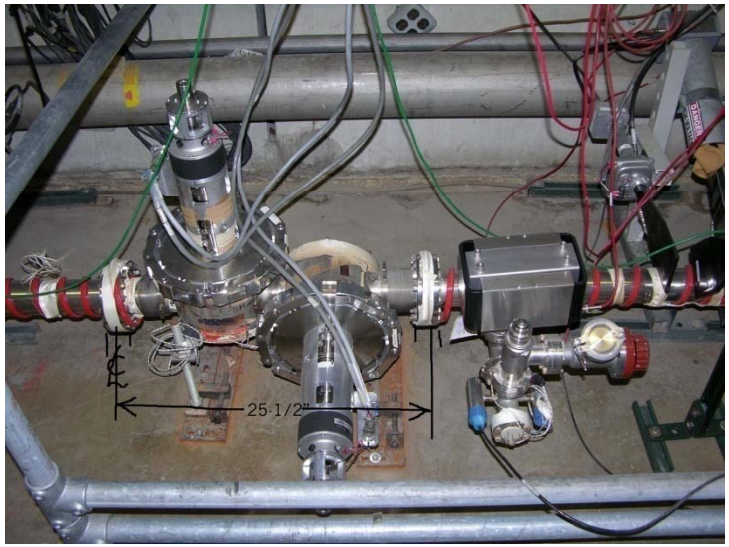


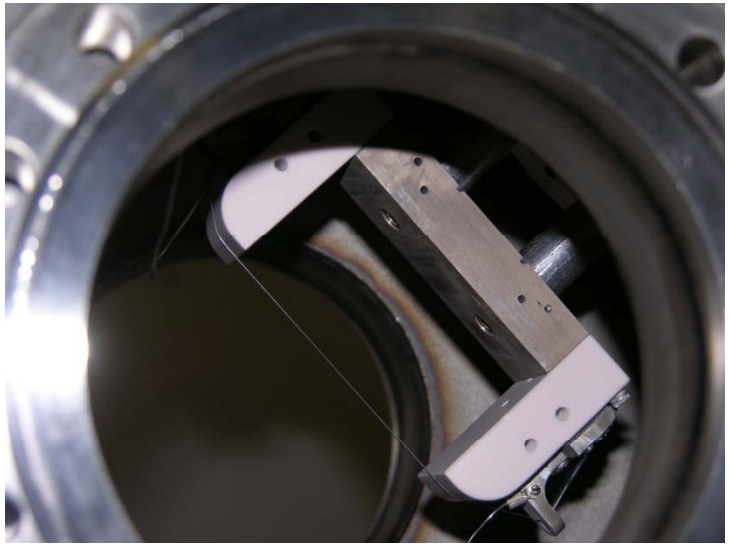
Signal:

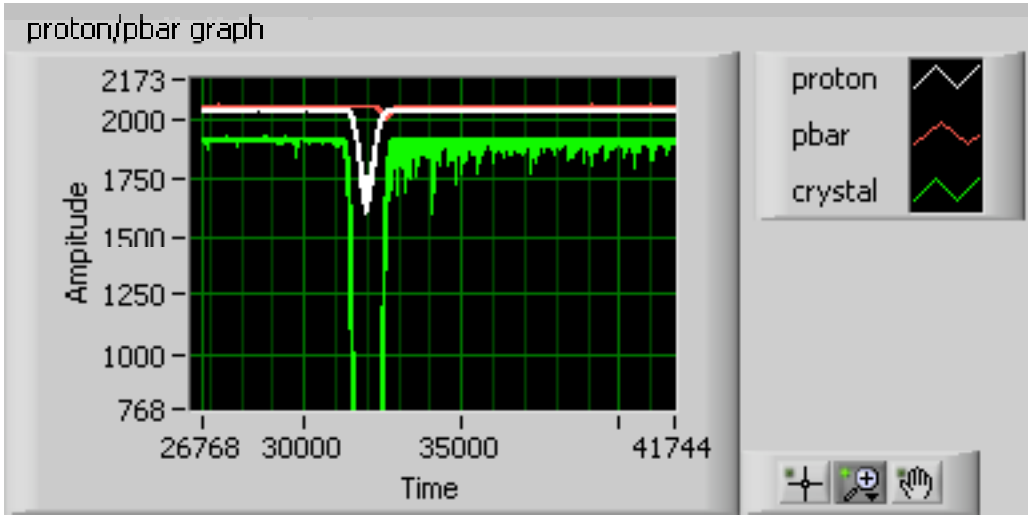
- increased rates in counters
- decreased rates in PIN diodes

S. Shiraishi, R. Tesarek

Flying Wires at E11





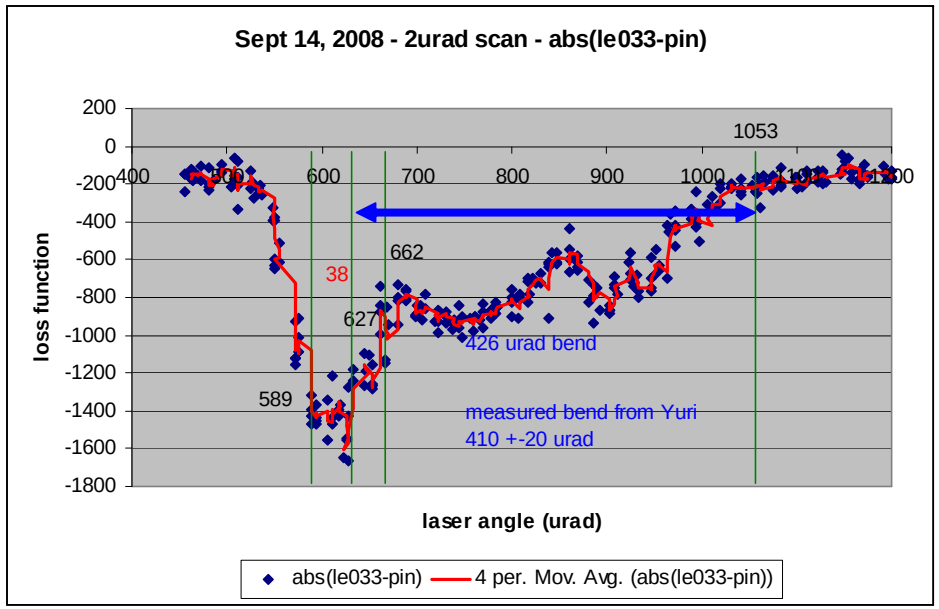


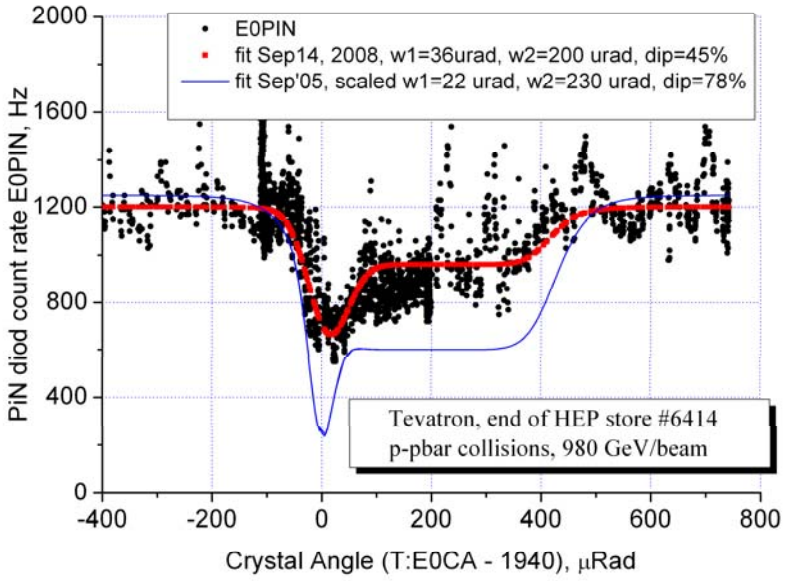
J. Zagel, S. Shiraishi, R. Tesarek

FIRST T980 BEAM TESTS (1)

Sept. 14, 2008: First End-of-Store (EOS) study (3 hours) with the new setup:

- aligning crystal
- first angle scan produced channeling results!





Analysis by V. Shiltsev

FIRST T980 BEAM TESTS (2)

Oct. 3, 2008: Second EOS study (5 hours) with the new setup:

- angle scan results are reproducible!
- problems revealed with laser and angular motion drift (fixed on Oct. 23).
- possible problem with relative positioning of the xtal and EO3 collimator at the EOS.

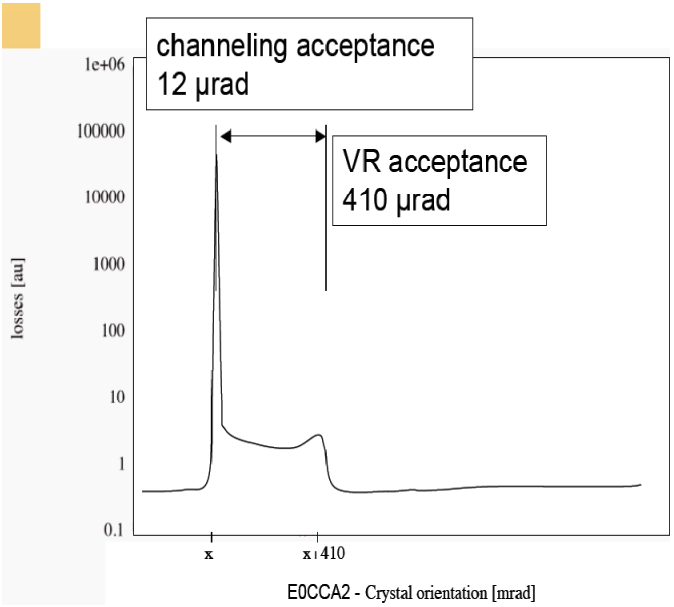
Several more EOS studies in 2008 and early 2009.

Excellent analyses by Valentina Previtali during her two-month visit at Fermilab (see her talk).
She will give a talk at PAC09 for the T980 Collaboration.

Beam Loss Localization vs Crystal Angle Scan

The outcome of End-of-Store studies (EOS) since September 2008 is quite positive. Results are reproducible, not so clean signal in 2008, now is OK.

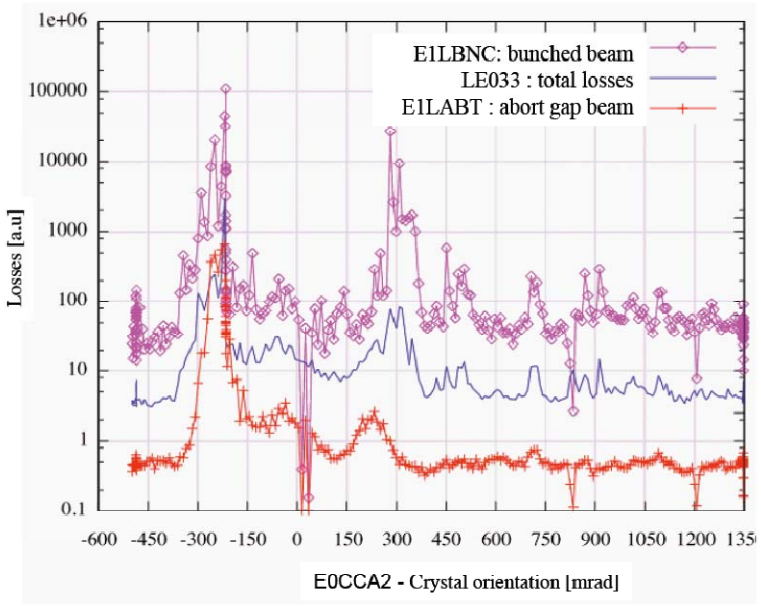
Theory



The ideal behaviour:

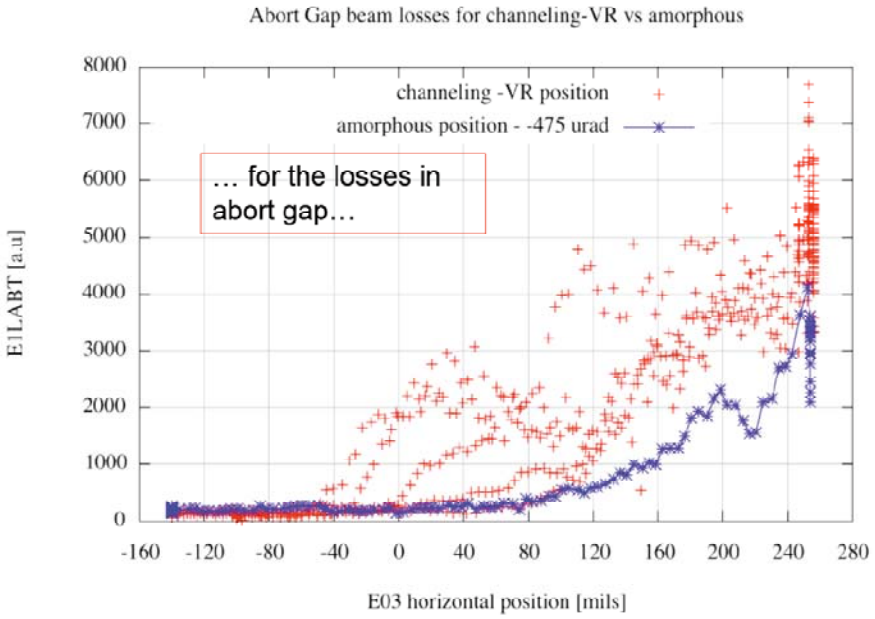
- clear channeling region, width of 2*critical angle (12 μrad)
- clear volume reflection region, acceptance = channeling angle (410 μrad)
- maybe a bump at the end of the VR region (as foreseen by simulations)

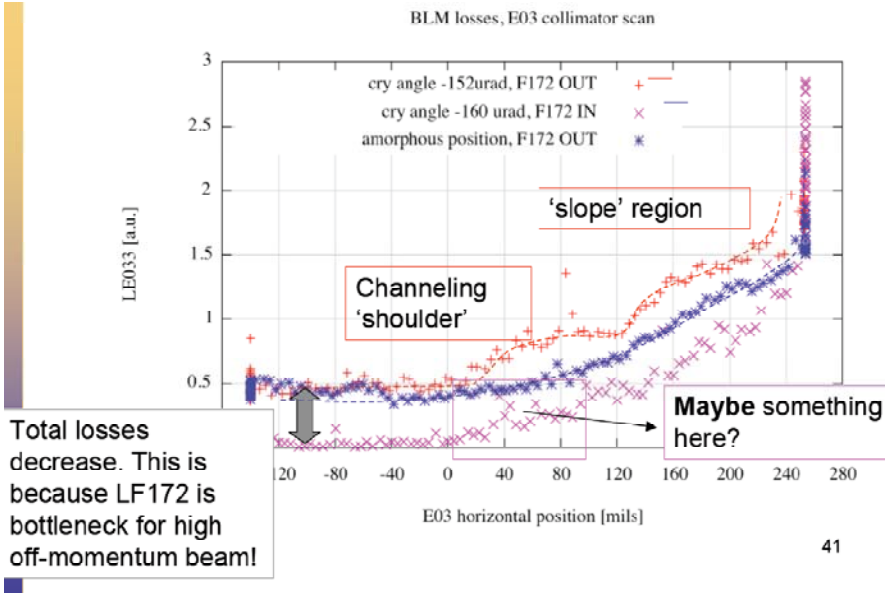
Data



Beam Loss Localization vs E03 Position

Channeling improves localization!





Other collimator positions need to be tuned for the crystal collimation!

Practical aspects of crystal collimation are much more delicate than those in conventional two-stage collimation system!

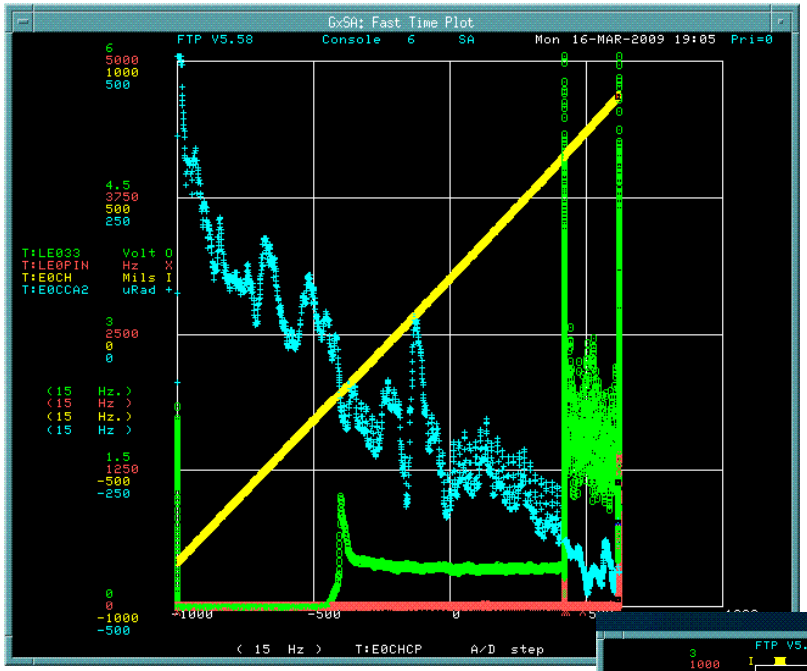
BOS Crystal Collimator Review, Feb. 4, 2009

Chaired by Roger Dixon with AD, CDF and D0 representatives on the Committee: review the progress of T980 and determine whether the experimenters should be allowed to insert the crystal into the Tevatron beam at the beginning of the collider stores.

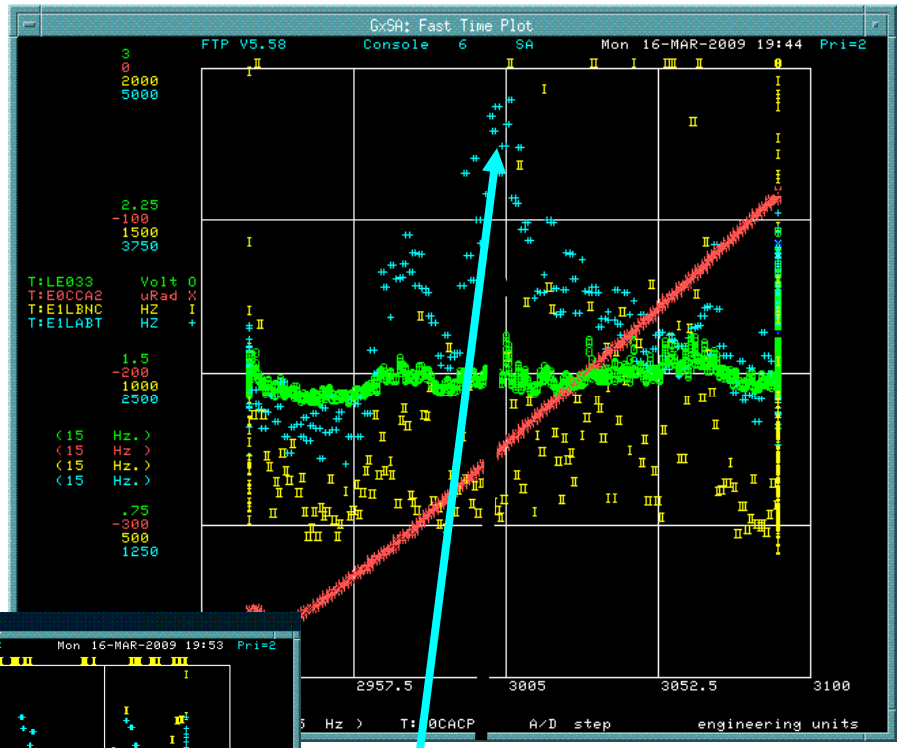
The studies since September 2008 have demonstrated that the crystal can be moved into the beam without causing undo losses. In addition, there is some evidence that the crystal could lower losses at CDF and D0. To make further progress the group has asked to put the crystal in at the beginning of a store.

It was agreed that the beginning of store studies should be initiated at the discretion of the Run Coordinator. The goal of these studies should be to establish normal operating parameters and to more effectively determine the performance of the crystal.

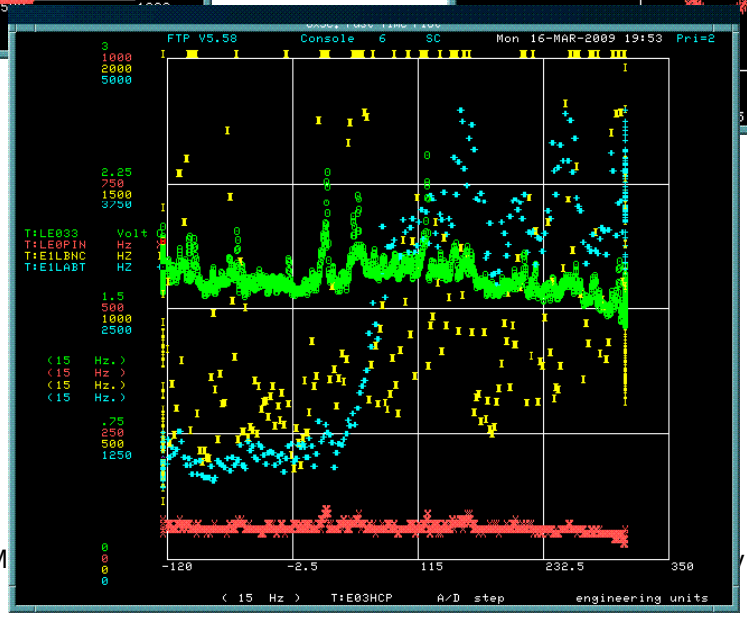
March 16, 2009, End-of-Store Study



Auto insertion of crystal horizontal, worked well



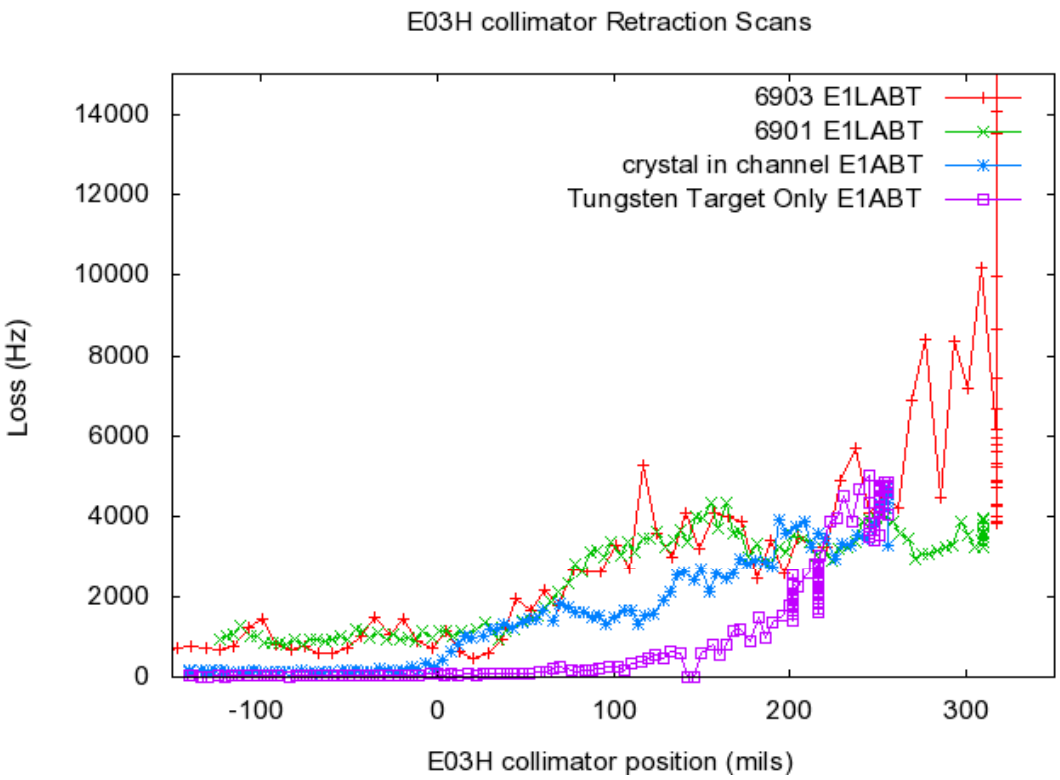
Setting the crystal angle to channeling



After angle set to channeling, completed E03H scan to verify

D. Still

First Use of Crystal for the Entire Collider Store



March 17-18, 2009

1. Successful test of crystal automatic insertion with no impact on the store.
2. Evidence of better cleaning.
3. Found angular drift over the entire store (heating?)

Flying Wire Sensitivity to Channeled Beam (1)

HG/LG Counter Sensitivity

$$s \geq 10\sigma_{pedestal}\sqrt{\delta x_{meas} L \theta_c}$$

Quantity	value	units
θ_c	10×10^{-6}	radians
L	33115	mm
δx_{meas}	0.083	mm
$\sigma_{pedestal(LG)}$	0.925	10^9 protons/mm
$\sigma_{pedestal(HG)}$	0.261	10^9 protons/mm

$s_{LG} > 1.53\times10^9$ protons
$s_{HG} > 0.43\times10^9$ protons

How does the sensitivity compare with expected signal size?

R. Tesarek

Flying Wire Sensitivity to Channeled Beam (2)

Expected lost signal size:

- Particles loss rate: ~ 1×10^{6}/sec (N. Mokhov)
- Bunch integration time: ~60×10^{-9}sec
- # bunches: 36
- # samples in deflected beam: ~ 20
- # particles in sample: ~ $1 \times 10^{6} * 60 \times 10^{-9} * 36 * 20$ = 42 protons

High Gain Counter Sensitivity = 0.4×10^{9}

Need increase signal by ~10^{8}

Typical "high gain" PMT has gain of ~10^{6}

Unlikely we can use flying wires to "see" channeled beam.

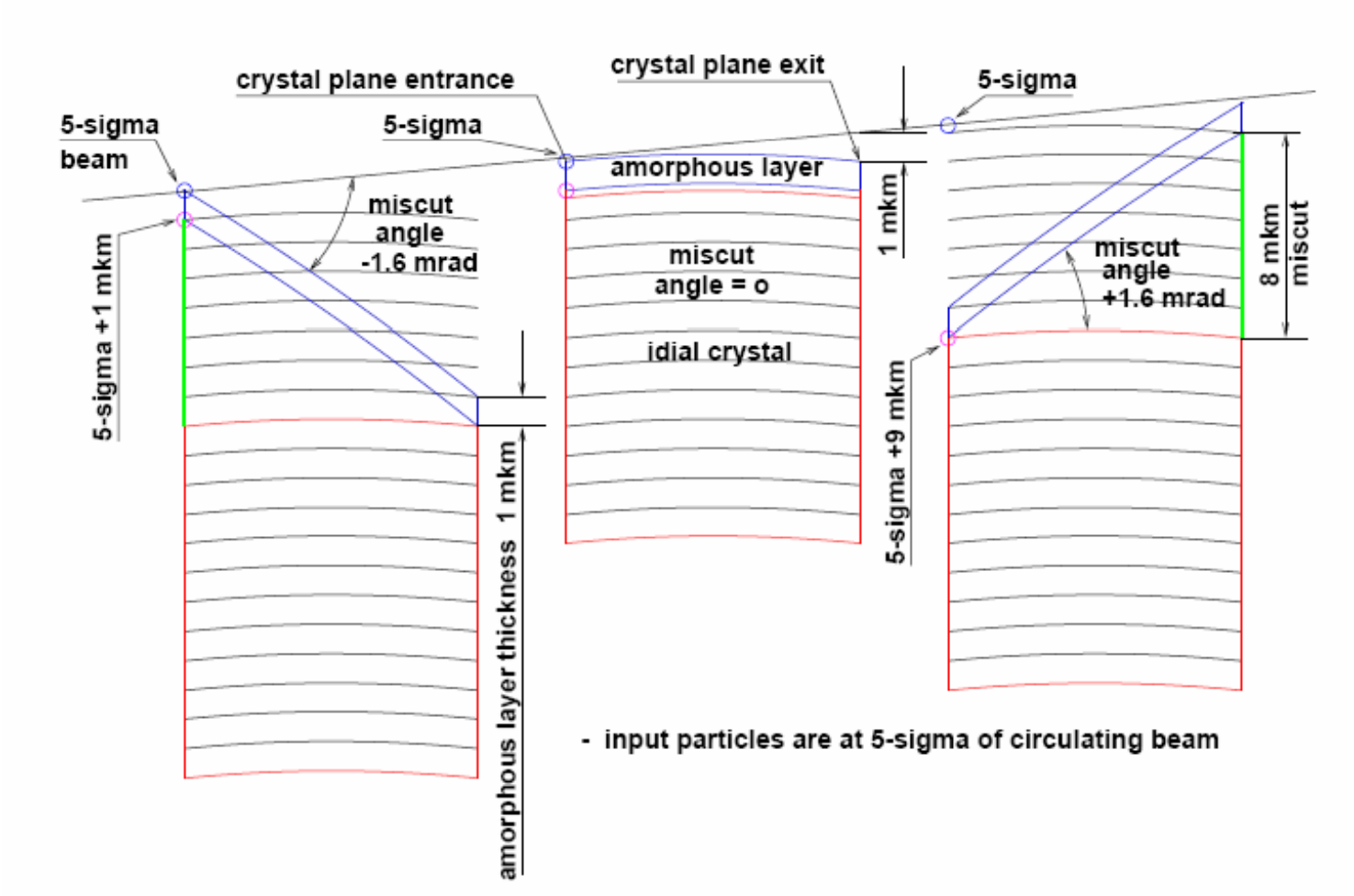
R. Tesarek

Computer Modeling for T980

- About a year ago, the Collaboration switched from CATCH to Igor Yazynin's CRYAPR code.
- Since then, numerous improvements, extensions and tests by Igor, Sasha Drozhdin, Armen Apyan and Bob Noble.
- Converging to a stable documented version.

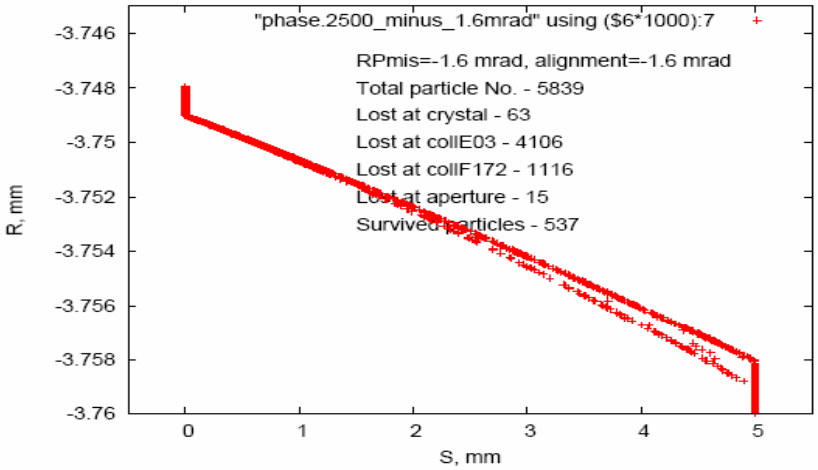
- Studies at FNAL with STRUCT/CRYAPR package: detailed simulations in the real Tevatron lattice with all the apertures included, focusing on the effect of miscut angle, beam profiles at critical locations, and optimizing new goniometer configuration.
- Studies at IHEP: modeling to make a crystal choice for new goniometer.
- Studies at SLAC: electron beams.
- Studies at BNL by G. Robert-Demolaize.

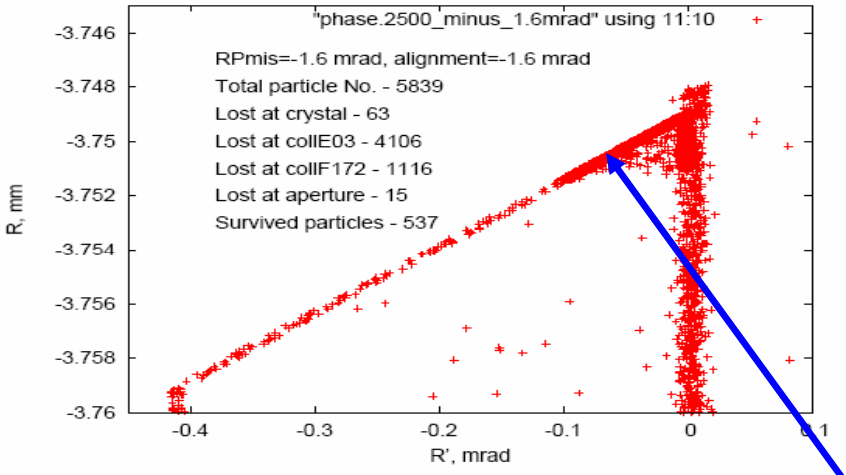
Computer Modeling for T980

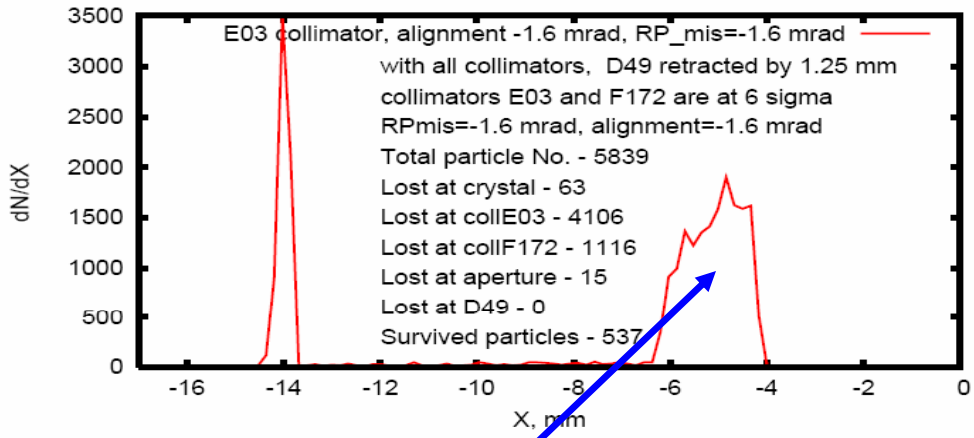


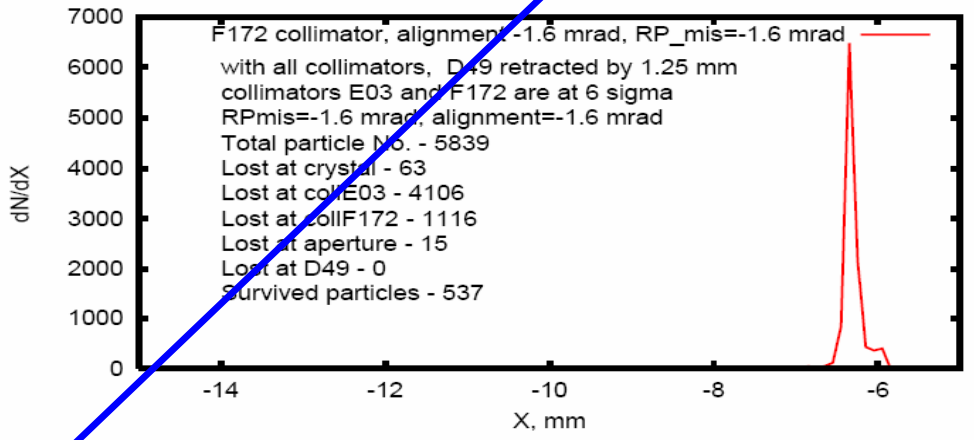
Modeling for T980: Studying Miscut angle ±1.6 mrad

Negative miscut angle of -1.6 mrad





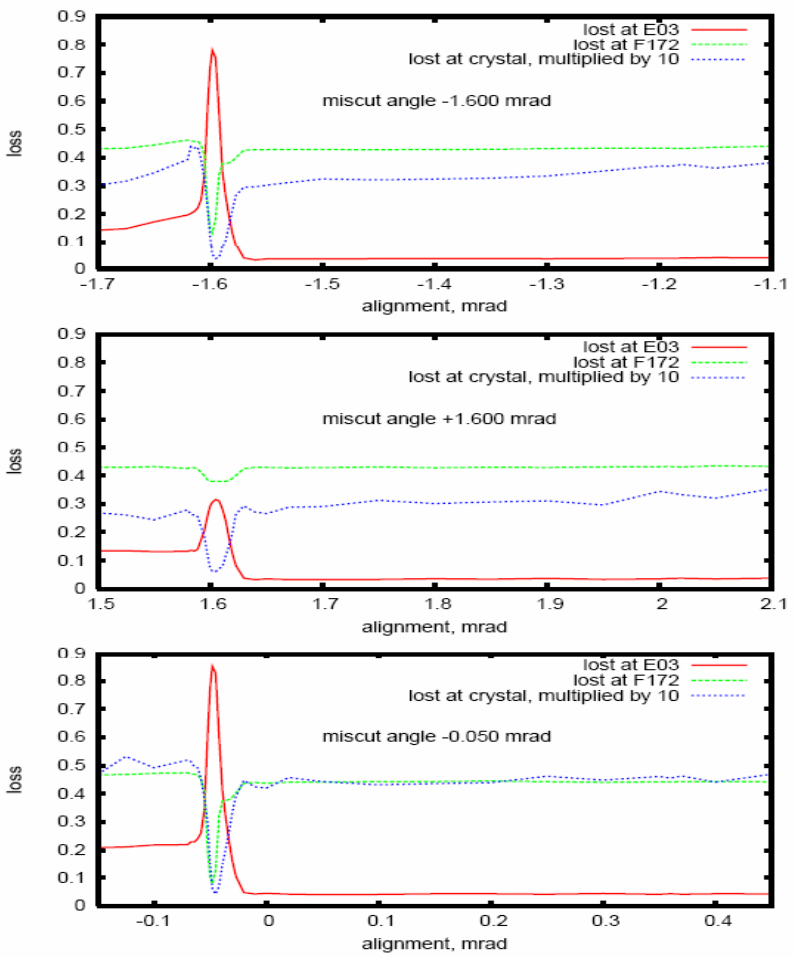




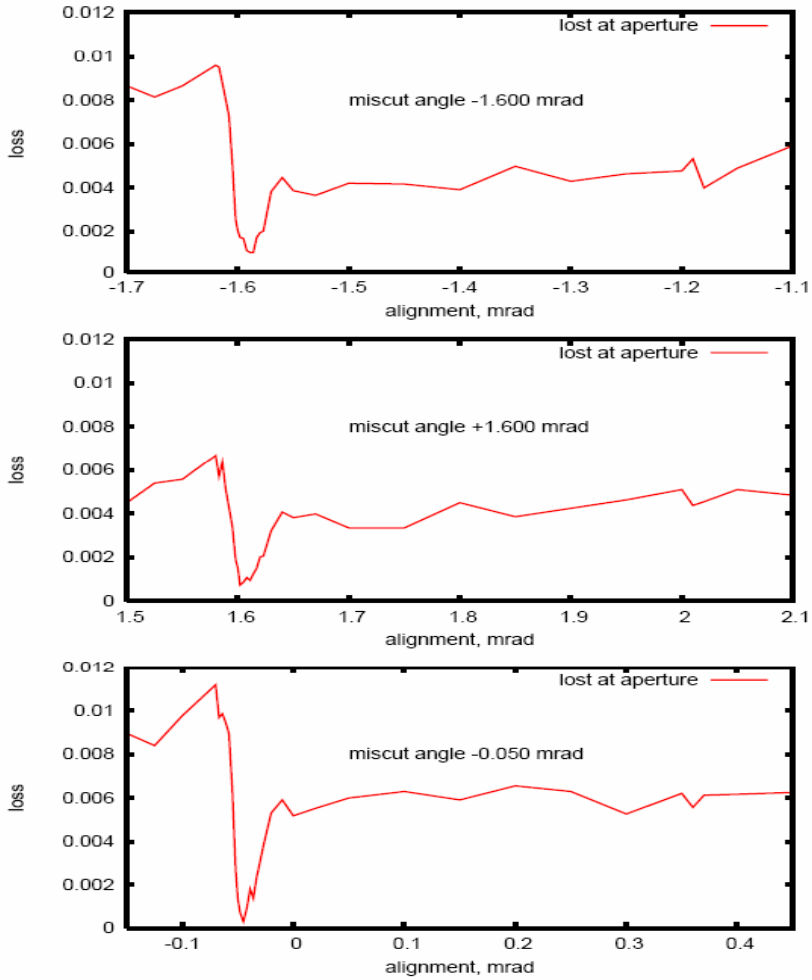
Partial channeling

STRUCT/CRYAPR Beam Loss Predictions

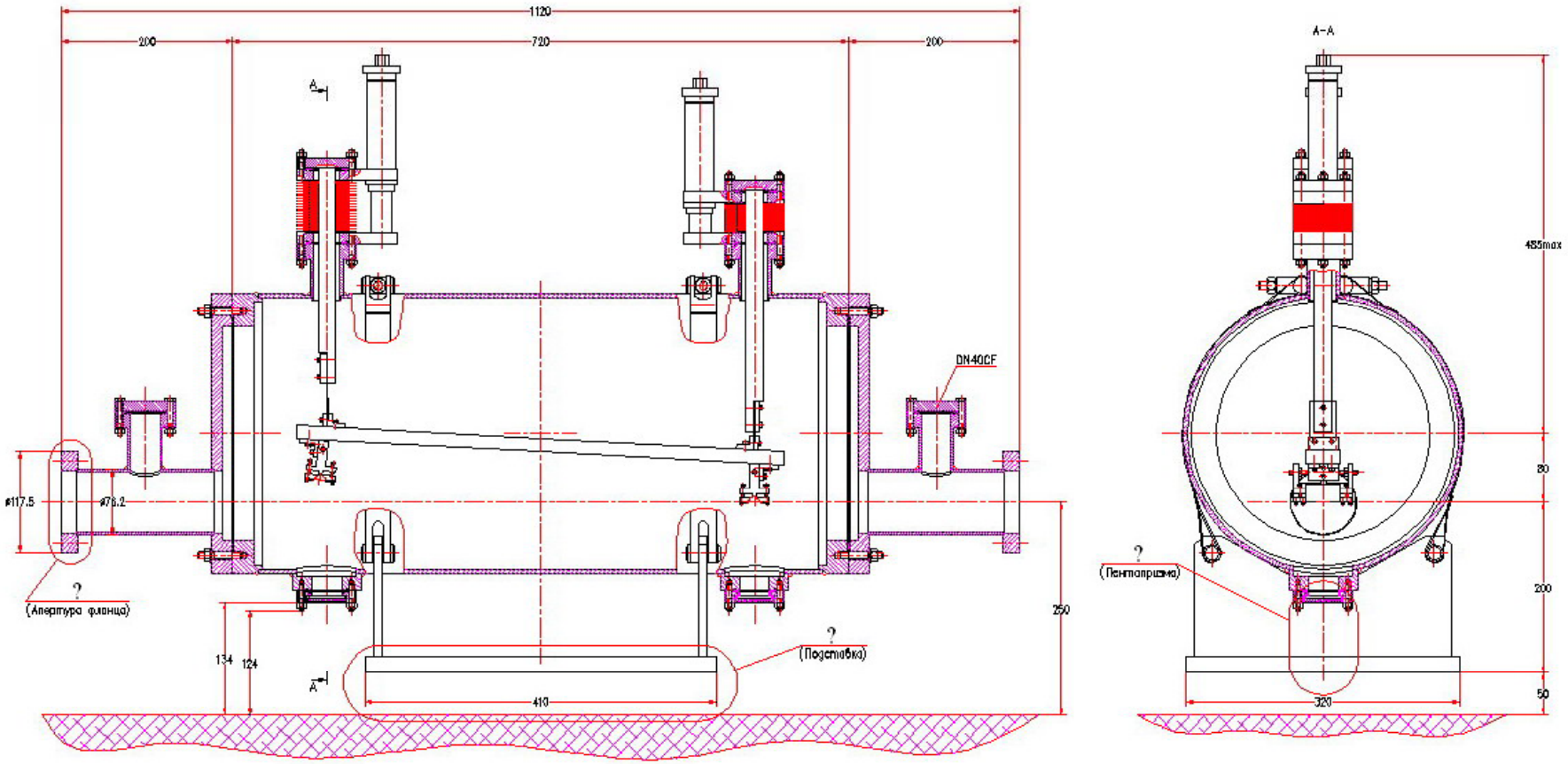
E03 and F172 collimators and xtal



Rest of the Tevatron



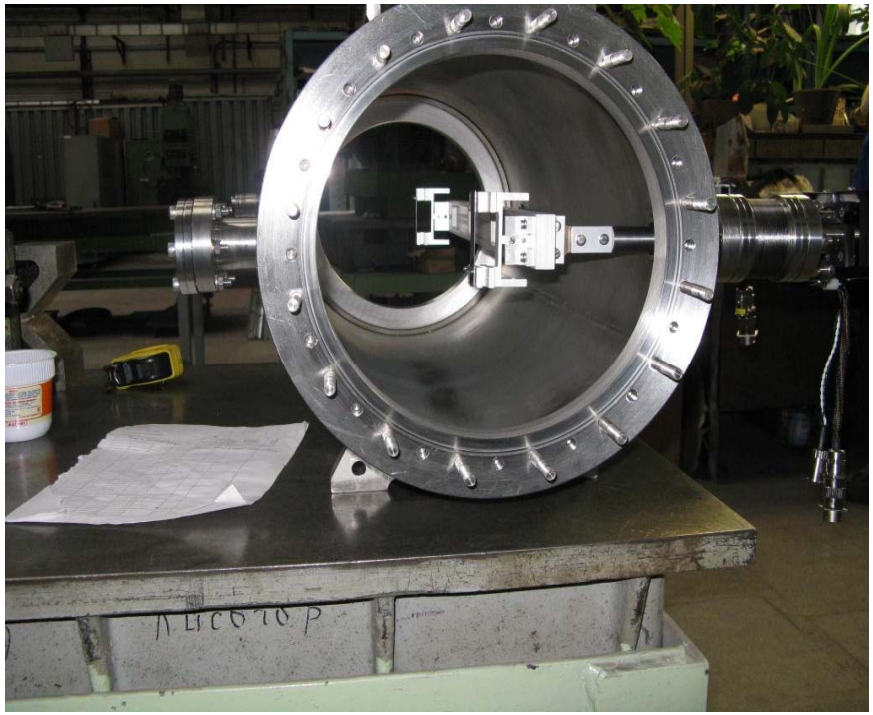
New Two-Crystal Vertical Goniometer by IHEP

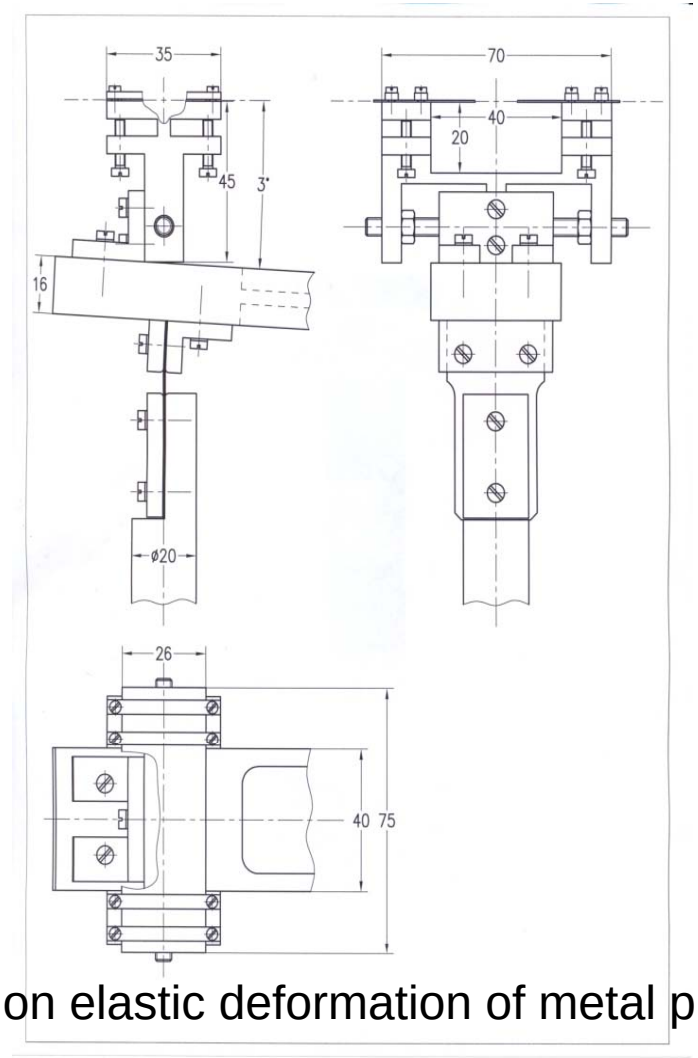


To be delivered to Fermilab in May 2009 along with two new crystals (with minimal miscut angle) for installation in TeV tunnel in June

IHEP Two-Crystal Goniometer

Linear step – 0.1 micron,
angular step 0.2 microrad





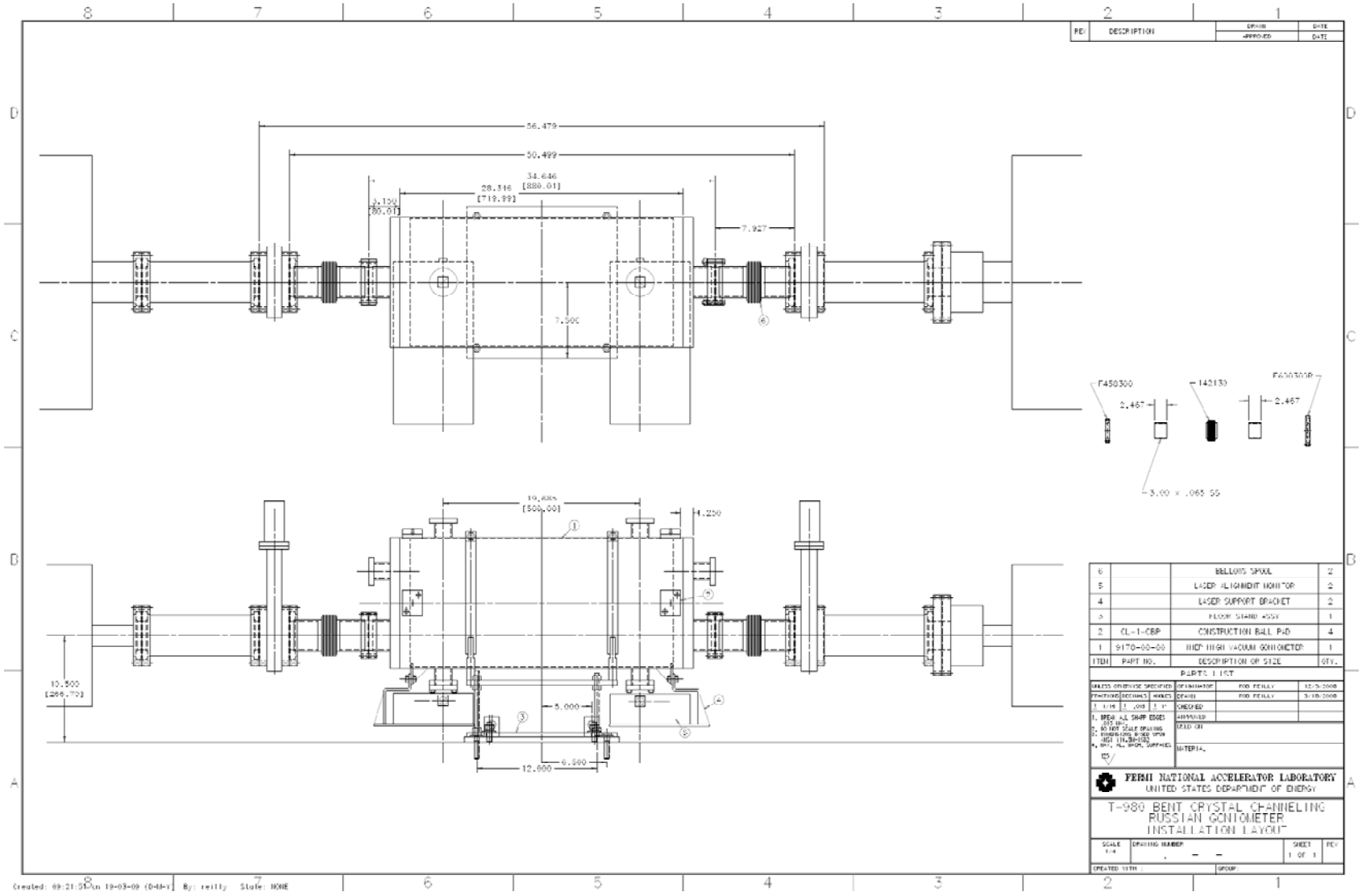
No friction details inside –rotation is based on elastic deformation of metal plate

IHEP Two-Crystal Goniometer

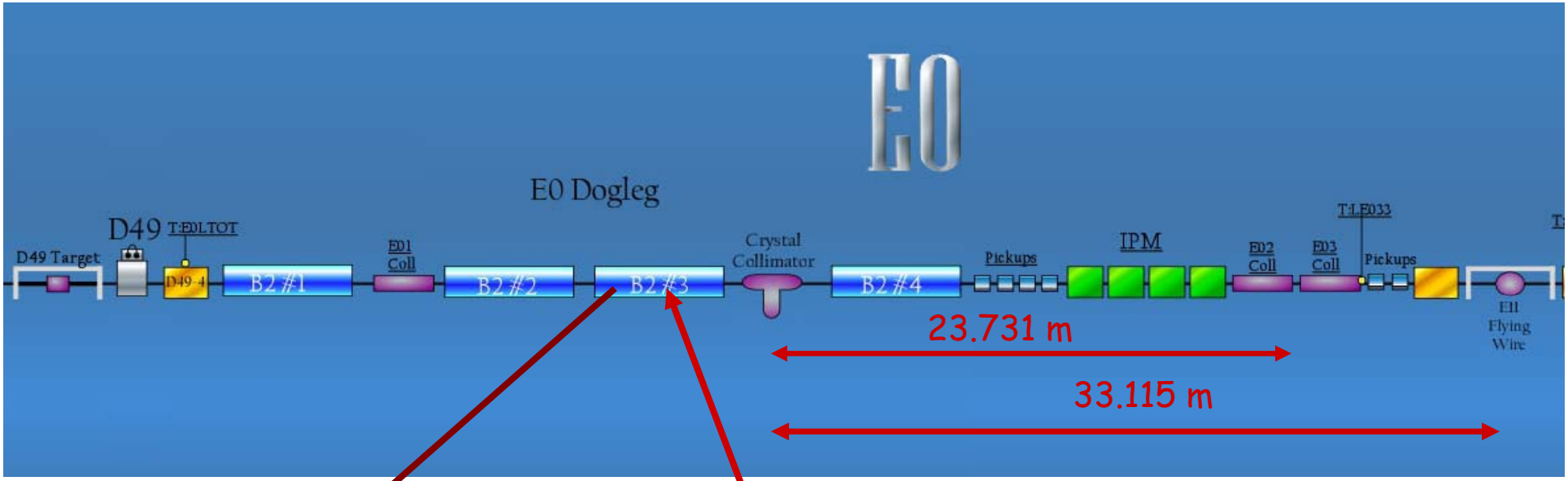
Vacuum and mechanical testing

Flanges are manufactured for Tevatron beam-pipe

Goniometer Installation Layout



New Vertical Goniometer Location



Remove B2-3 dipole

Install new goniometer here
Alternate crystals without breaking vacuum !

Plans for 2009 through Beginning of 2010

1. Continue BOS aiming at convincing reproducible loss reduction in the machine, CDF and D0; first, fix the angular drift problem for the entire store (15-20 hrs *vs* 2-hr EOS), insulate goniometer if heating is the problem.
2. Investigate alternatives to Flying Wire for beam profile measurements.
3. Install the new vertical goniometer at E0 ~2 m upstream of the horizontal one; in September 2009 start beam tests with it; study performance of alternating crystals of two different technologies: O-shaped (channeling) and multi-strip (VR).
4. Start two-plane beam cleaning with horizontal and vertical crystal collimators simultaneously.